

# Ultra-light Door Design, Manufacturing, and Demonstration

2019 Vehicle Technologies Office  
Annual Merit Review Washington, DC  
June 11, 2019

**Presenter:** Tim Reaburn, Magna International

**Recipient :** Vehma International

**Subrecipient:** FCA US LLC

**Subrecipient:** Grupo Antolin NA

**Subrecipient:** Magna Closures Inc

**Subrecipient:** Magna International

## Timeline

Start Date: 2015-Dec

End Date: 2018-Dec

## Budget

Total Project Funding	\$ 8,444,582
• DOE:	\$ 4,222,291
• Industry	\$ 4,222,291

Actual Costs Incurred	\$ 6,785,872
• DOE:	\$ 3,392,936
• Industry	\$ 3,392,936

*Budget vs Actual cost differential primarily associated with a reduced costs of validation testing*

## Barriers & Technical Targets

- 42.5% mass reduction from baseline current model of Chrysler 200 Front Driver Side Door
- \$5/lb weight saved not to exceed incremental cost
- maintain the functionality and performance of the baseline door assembly

## Accomplishments

- 40% mass reduction
- \$2.81/lb weight saved
- maintained functionality and durability and safety performance of the baseline door assembly

## Technology Partners

### Recipient

Vehma International of America

### Subrecipient

FCA US LLC

Grupo Antolin NA

Magna International Inc

Magna Closures Inc

### Industry Partners

Arplas USA LLC

Corning Glass

Lindita Bushi LLC

Alpine Electronics of America, Inc

- **Mass Reduction:** A driver's side door mass reduction of 15.2 kg provides an estimated full vehicle mass reduction of 54kg per vehicle (30kg front, 24kg rear).
- **Architecture:** The “frame behind glass” door architecture associated with the Ultralight Door is applicable to 70% of the car and light truck vehicle market, which totaled 17.3M vehicles in 2016 (16.9M in 2018)
- **Fuel Reduction:** A 54kg mass reduction can enable a reduction of 0.26 liter/100km fuel consumption when combined with an appropriately downsized engine to maintain the same level of performance.
- **CO<sub>2</sub> Benefit:** A 0.26 liter/100 km fuel reduction provides 6 g/km CO<sub>2</sub> or 9.6 g/mile CO<sub>2</sub> reduction.
- **Cost Effective:** The \$2.81 per pound saved cost model estimate provides a cost effective means to reduce CO<sub>2</sub> emissions.

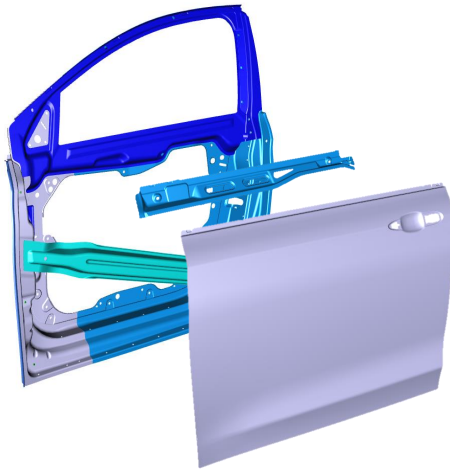
# Milestone Status

Milestones	Completion Date	% Complete
Project Management	2018-Dec	100%
Architectural Design	2016-Feb	100%
Concept Design	2016-Apr	100%
Final Design	2016-Nov	100%
Technical Cost Model	2016-Nov	100%
Manufacture Prototype Parts	2017-Apr	100%
Assemble Prototype Parts	2018-May	100%
Component- and Vehicle-level Testing	2018-Sept	100%
Final Report	2018-Dec	100%

# Program Approach

1

**Vehicle Platform Selection**  
- Midsize Sedan/C-Segment

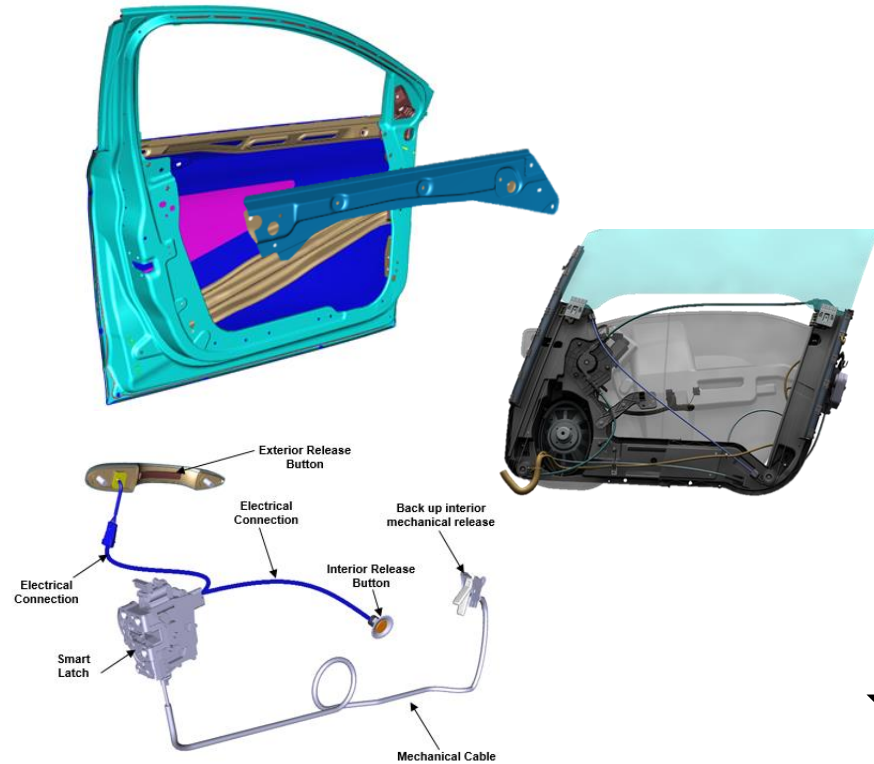


2

**General Structural DIW Architecture**  
(Defined from Baseline Vehicle)  
- Frame behind Glass Architecture

3

**Complete Door Sub-System Architecture Optimization**  
- Eliminate redundant material/structure (weight and \$ efficiency)



4

**Material Selection and Design Optimization**  
- Select materials that will meet optimum cost/weight objective

# Program Approach

## Step 1 - Vehicle Selection

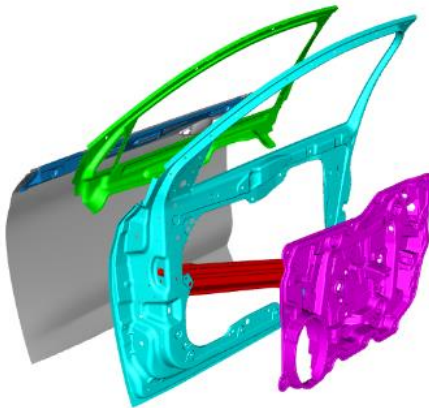
- **Chrysler 200 is a D-Segment** vehicle which represents **35.6% of the 2014 US Market**

### Sales Volume by Segment

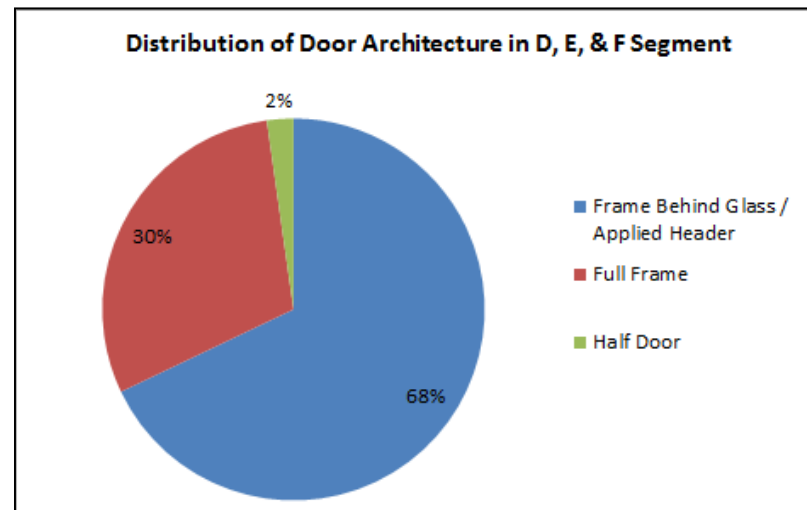
B – 3.9%  
C – 33.8%  
D – 35.6%  
E – 11.1%  
Pick-Up – 15.0%  
Other – 0.6%



- **Chrysler 200 uses Frame Behind Glass Door Architecture** which represents **68% of D Segment door design** (only A and Pick-Up Truck Segments use predominantly Full-Frame door design)



Chrysler 200 Door Architecture  
Frame Behind Glass

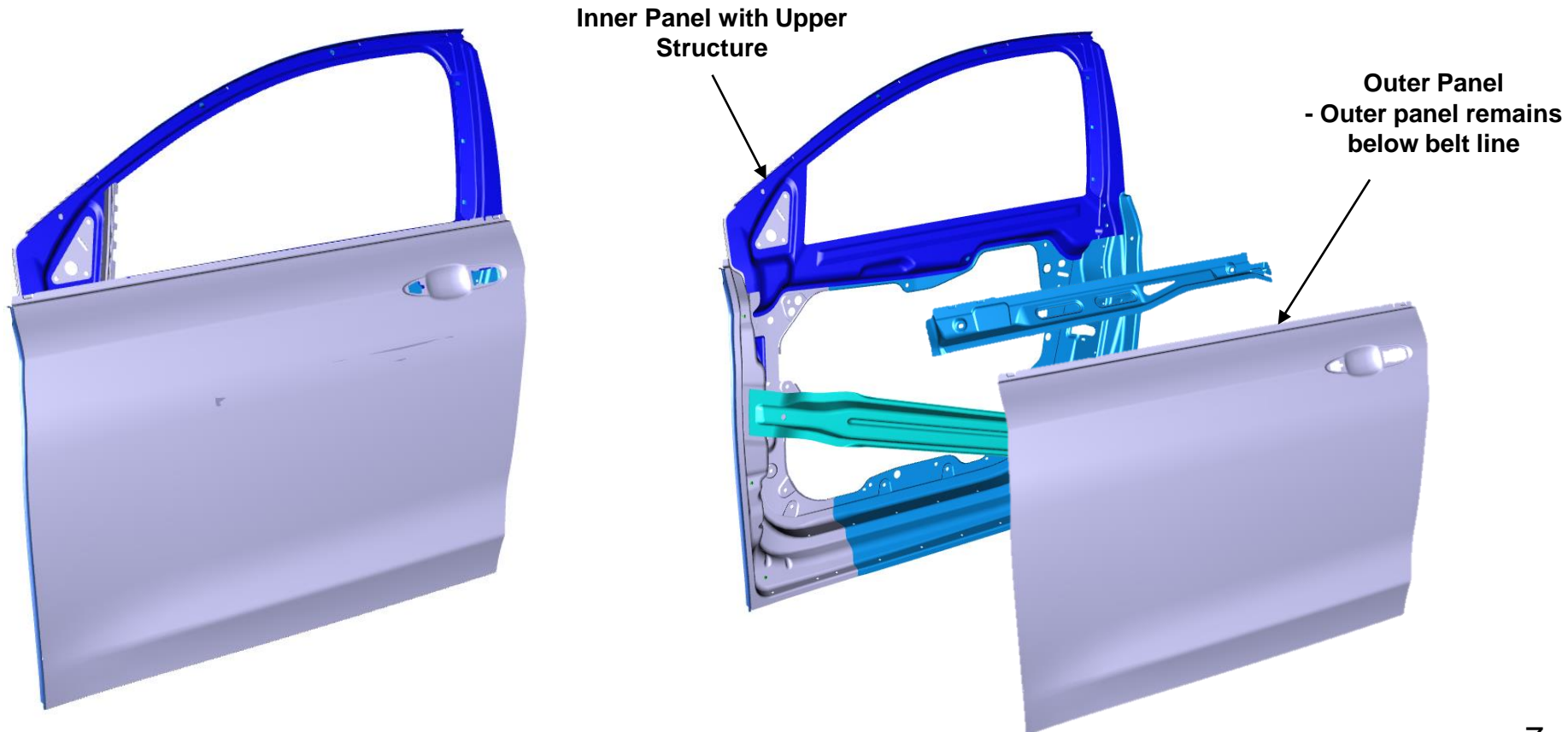


# Program Approach

## Step 2 - General Structural Architecture

Structural Architecture and panel breakup was predicated by the following:

- 1) Frame behind Glass Architecture
- 2) Seal Plane Location
- 3) Exterior Surface and Profile
- 4) Features and Functions
- 5) Safety/Durability/Stiffness Requirements

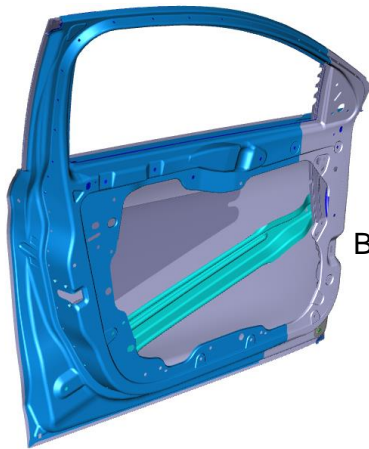




# Program Approach

## Step 3 - Complete Door Sub-System Architecture Optimization

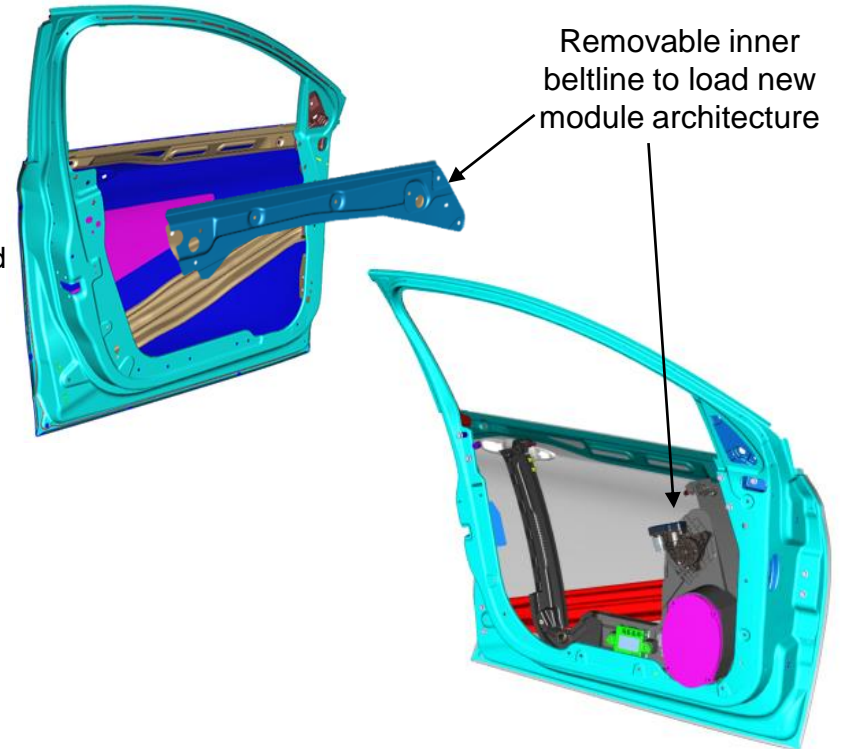
### Baseline Structural Architecture



Baseline Structural Architecture modified to incorporate Module Architecture



### LW Door Structural Architecture



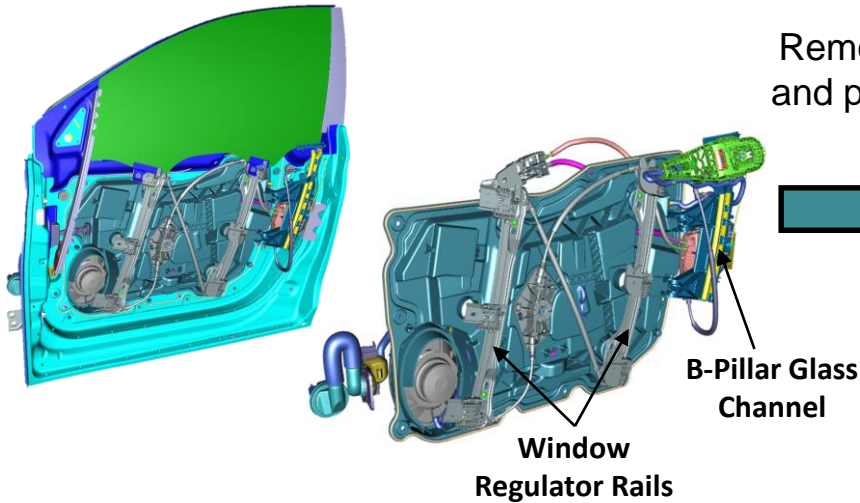
*The removeable beltline inner panel simplifies installation of the door module*



# Program Approach

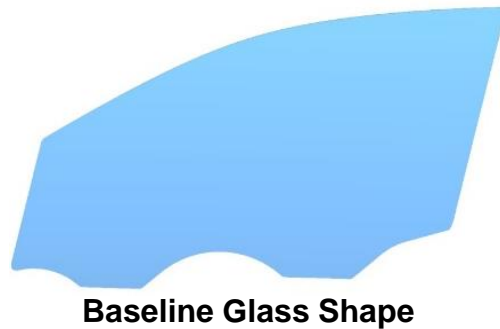
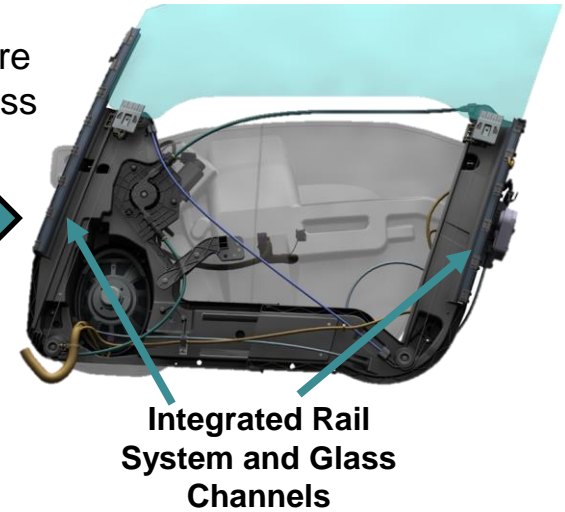
## Step 3 - Complete Door Sub-System Architecture Optimization

**Baseline Module Architecture**

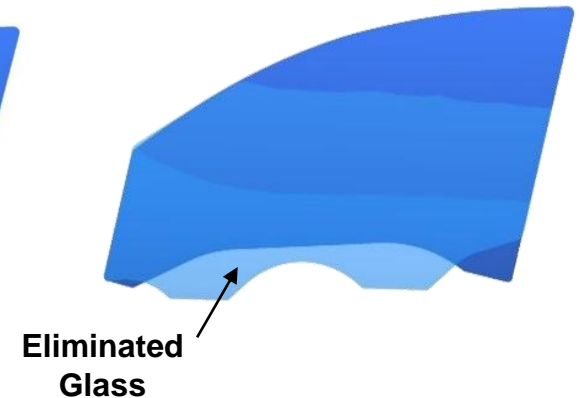
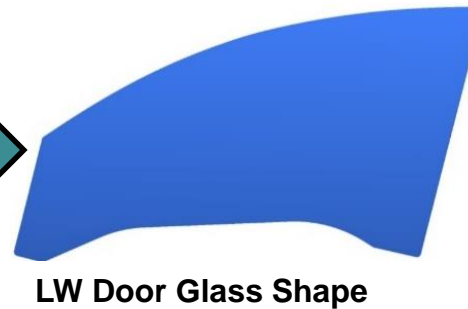


Remove redundant structure and parts by integrating glass channels and rails

**LW Door Module Architecture**



Glass surface area reduction



*New module architecture reduces glass surface area, eliminating glass*

# Program Approach



## Step 4 – Material Selection and Design Optimization

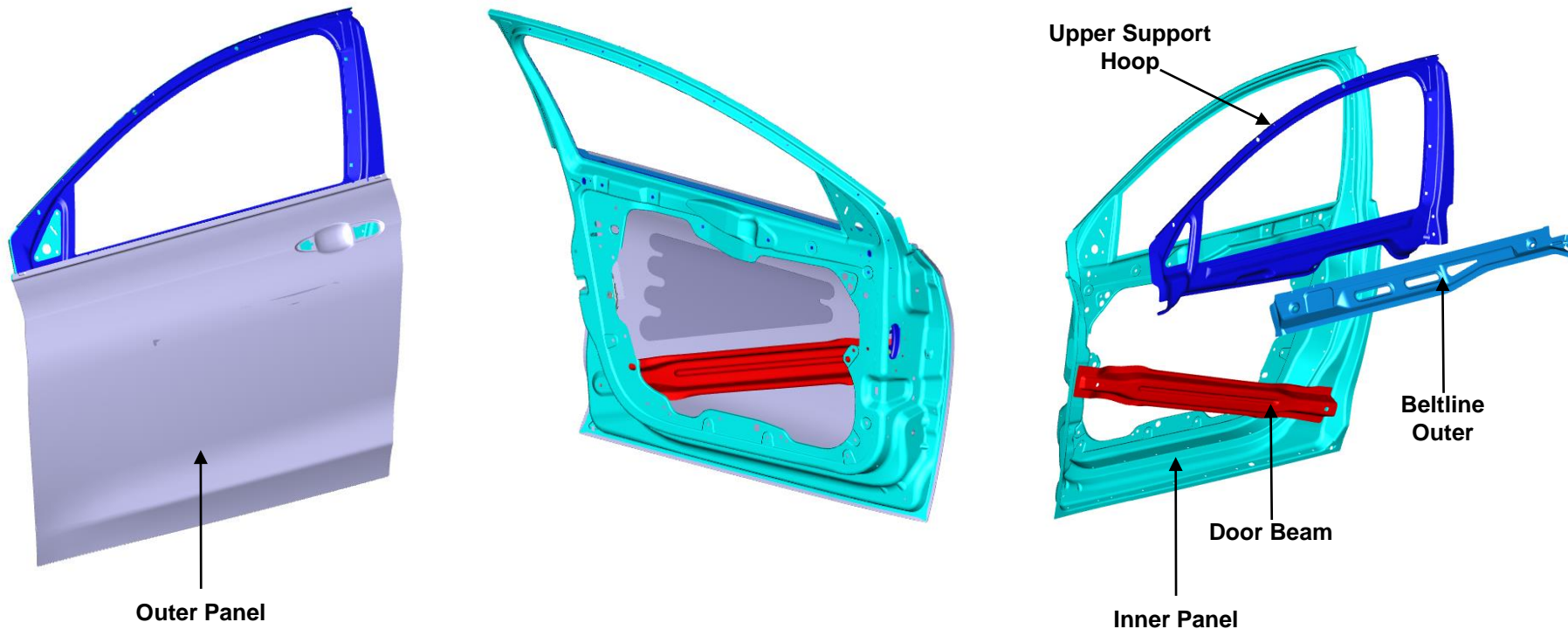
- DIW represents ~45% of door total mass and ~50% of cost
- Cost and weight analysis (\$/lb saved) conducted to determine material selection

Door Structure Primary Material	Door Structure Cost (\$/lb-saved)
HPD Cast Aluminum/Magnesium	\$8.50
Injection Molded Carbon Fiber	\$9.00
Stamped Aluminum	\$4.40

**Door  
Structure  
\$/lb-saved  
ONLY**

- Stamped Aluminum DIW was selected due to cost to weight savings while able to meet weight reduction target

### Baseline Door Structure



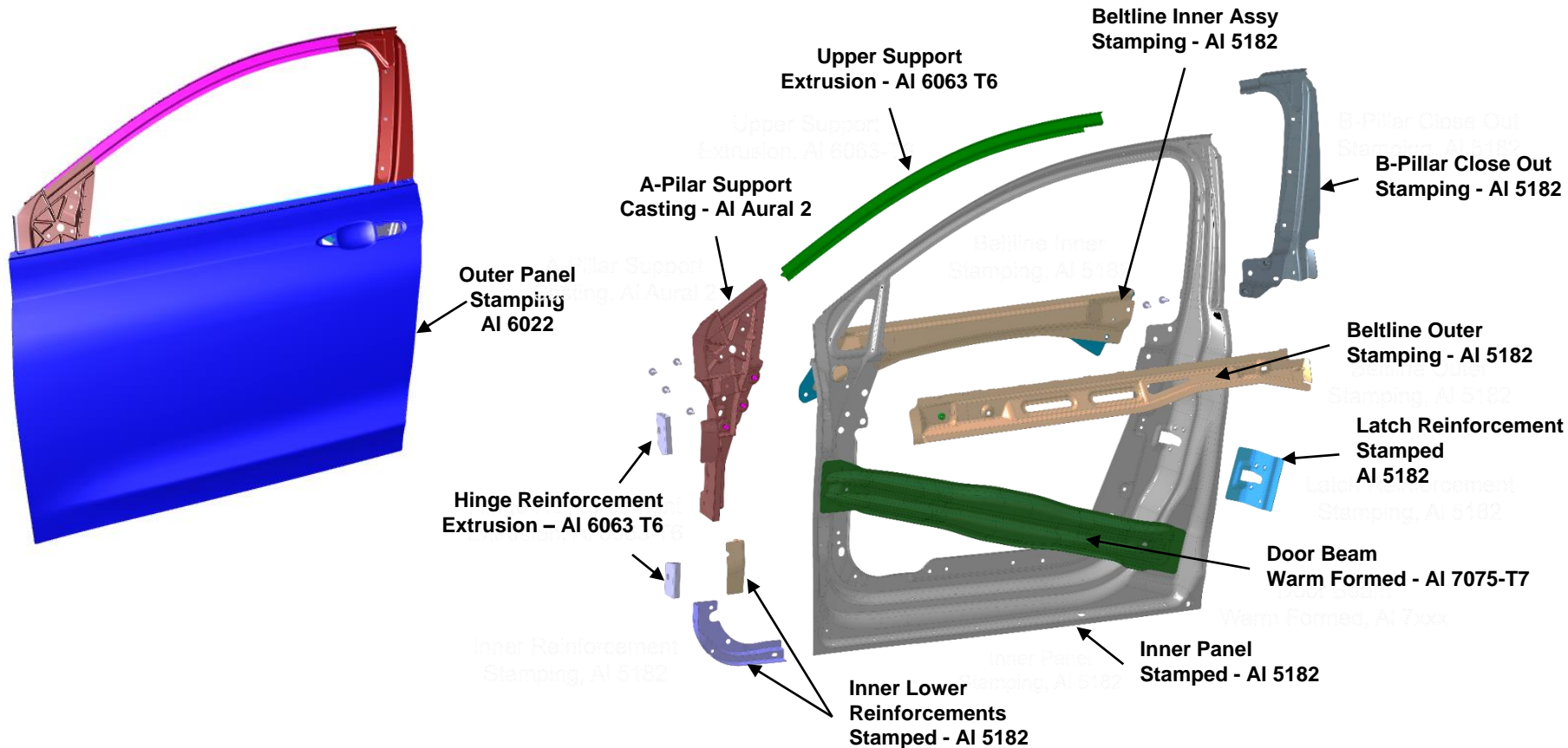
**Weight: 16.95 kg**

*The baseline Door Structure includes steel components and weighed 16.95 kg*

# Program Approach

## Step 4 – Material Selection and Design Optimization

### LW Door Structure



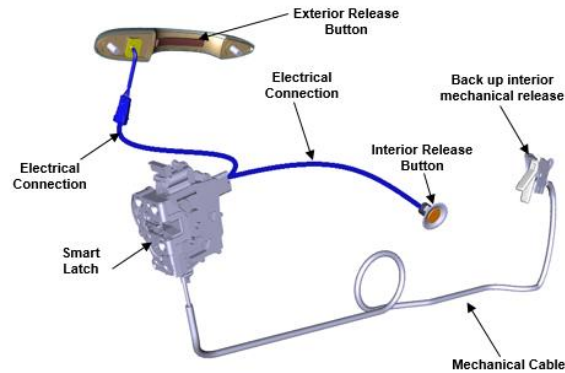
**Weight: 9.32kg**

*The LW Door Structure includes aluminum components and enables a 7.73 kg mass reduction*

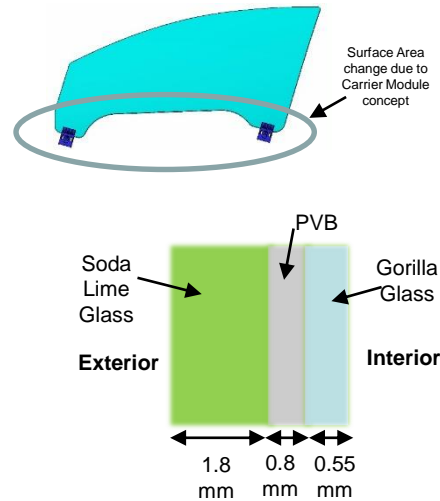
# Program Approach

## Mass Reduction by Subsystem

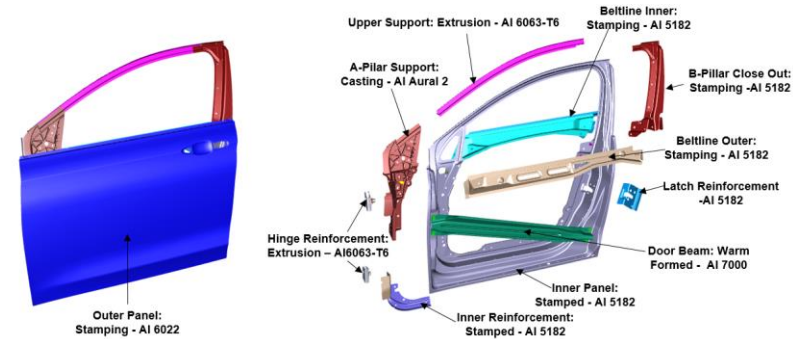
### Door Latching Mechanism – 58%



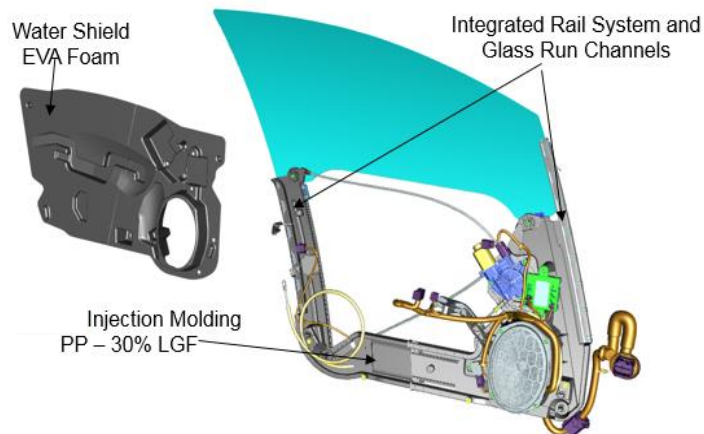
### Glass – 48%



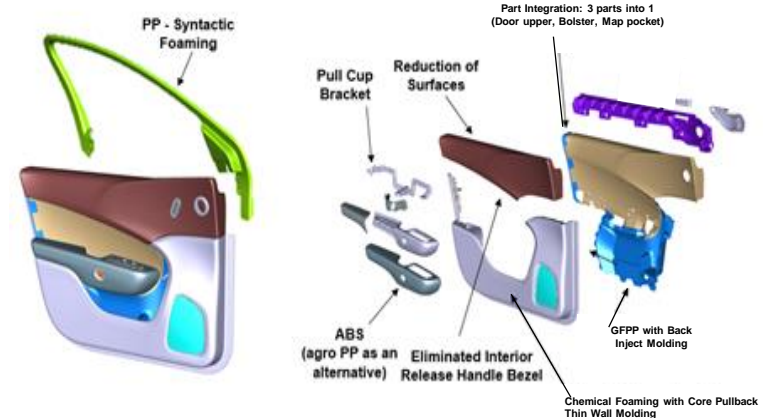
### Door Structure – 45%



### Door Module – 37%



### Interior Trim – 39%



*The LW door architecture enabled mass reduction of the various door subsystems*

# Program Approach

## Architecture vs Mass Weight Savings Breakdown

System	System Mass Savings (kg)	Architecture Change (%)	Material Change (%)	Comment
Door Structure	7.63	0	100	
Interior Trim Panel and Upper Trim	1.66	30	70	Redesigned architecture to eliminate redundant surfaces, combine parts, and allow light weight molding processes to be implemented.
Glass Assembly	1.97	21	79	Module architecture change accounts for surface area reduction
Window System/Door Module	1.05	100	0	Integrated window channels and rails eliminating redundant parts and structure.
Latch and Exterior Handle	0.84	100	0	Electronic latch eliminates mechanical cables and rods. Electronic latch eliminates exterior handle support structure and rotational counter mass.
Other	2.02	0	100	
<b>Total</b>	<b>15.17 kg</b>	<b>2.87 kg</b>	<b>12.37 kg</b>	



*2.87 kg mass savings due to architectural changes at an incremental cost of \$0 per lb-saved*



# Technical Accomplishments

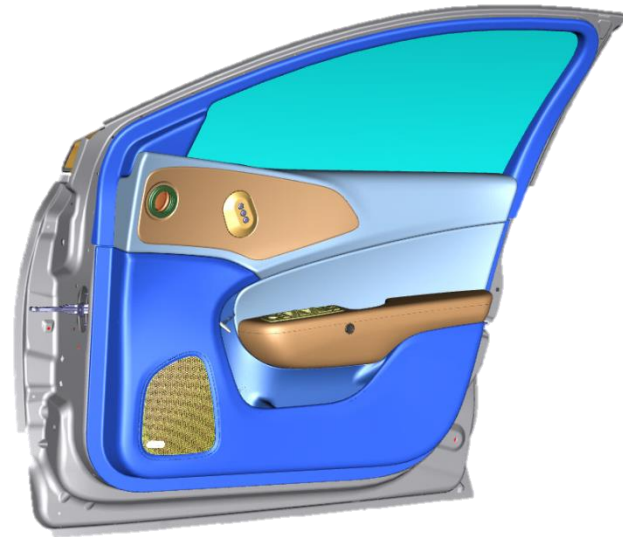
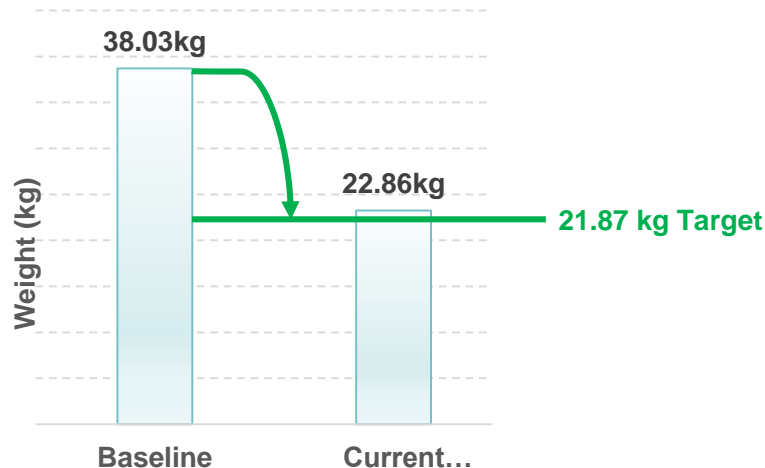
## DOE Target

42.5% Weight Reduction  
\$5/lb mass saved

## Status

40% Weight Reduction (15.17 kg)  
\$2.81/lb mass saved

## Current Status vs Goal



Mass reduction targets achieved by incorporating new design architecture and use of lightweight materials and advanced manufacturing technologies

*The 22.86 mass of the LW Door fell 1kg short of the 21.87kg target however the incremental cost per pound saved of \$2.81/lb significantly beat the \$5/lb saved target.*

# Technical Accomplishments

## Test Summary



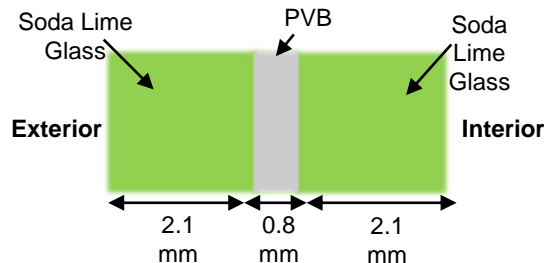
Type	Test	Result
Corrosion	Full Vehicle Corrosion	
Water Intrusion	Water Intrusion Test	
Safety	NCAP Side Impact Barrier – FMVSS 214 Dynamic Barrier	
	NCAP Side Impact Pole - FMVSS 214 Dynamic 5 <sup>th</sup> Pole	
	FMVSS 214 static	
Customer Satisfaction	NVH – Full Vehicle Wind Noise (Measured at Driver’s Left Ear)	Marginal Degradation
	Overall fit/finish	
	Appearance and Functionality (door aperture, gaps, swing)	
Structural Stiffness (from target matrix)	Sag-Set	
	Anti-theft	
	Static Over Check	
	Denting and Oil Can	
Durability	Window Cycles	
	Hardware Slam	

# Technical Accomplishments

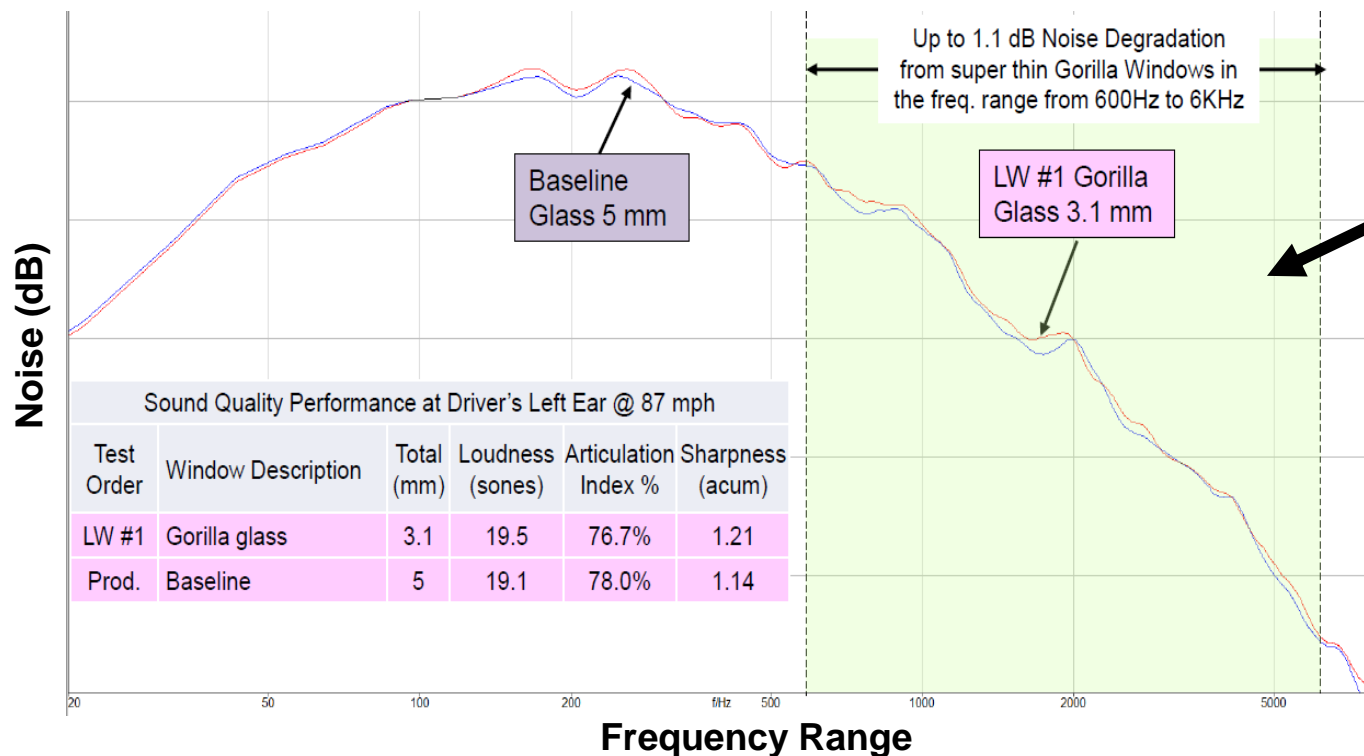
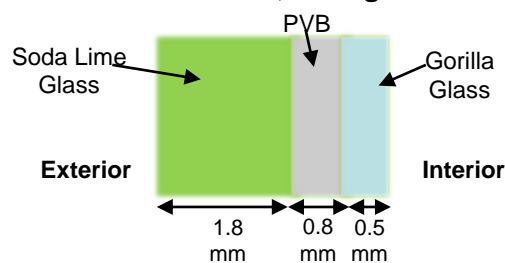
## NVH Full Vehicle Wind Noise

- Wind traveling over the vehicle at 87 mph, 0 degree yaw
- Wind noise measured at driver's ear (Aachen head)

**1) Baseline Door Glass Thickness**  
- 5mm, 4.12 kg



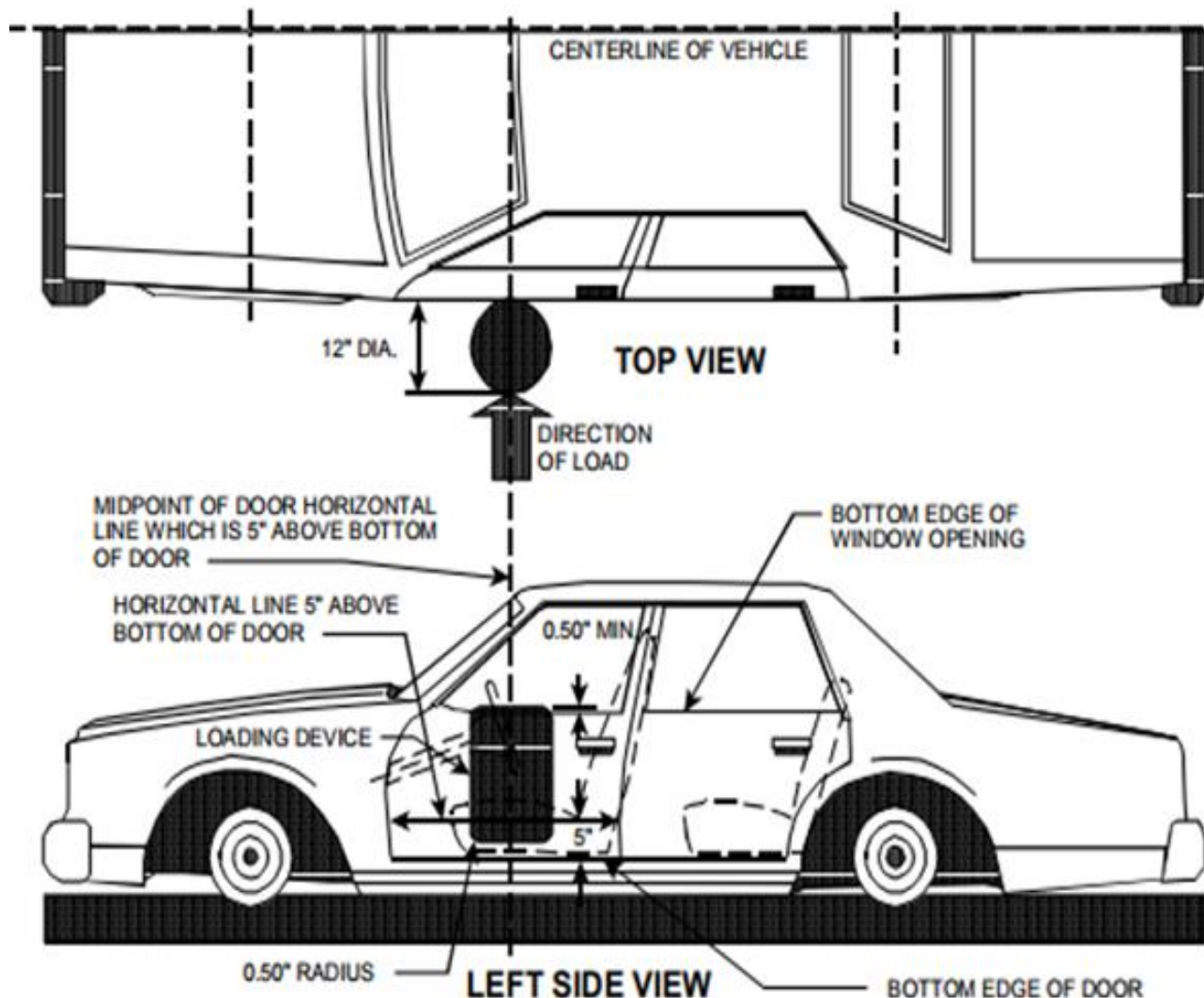
**2) LW Door Glass Thickness**  
- 3.1mm, 2.15kg



*Gorilla glass provided the opportunity to reduce glass thickness by 31.7% and improved noise degradation performance at 87 mph in the frequency range from 600 Hz and 6K Hz*

# Technical Accomplishments

## FMVSS 214 Static Test



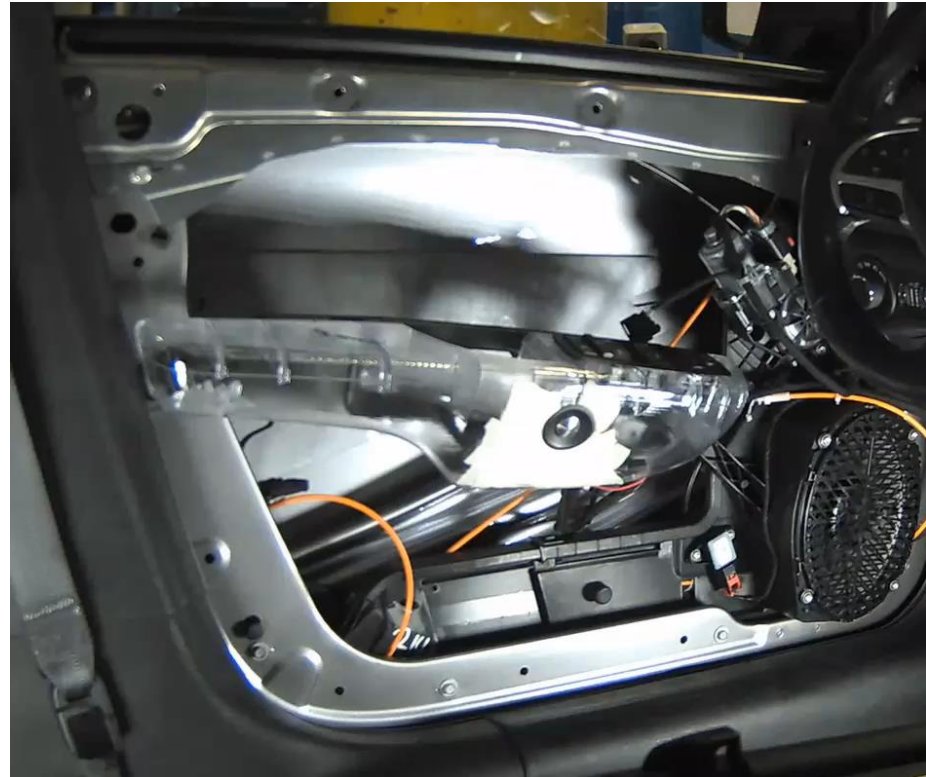
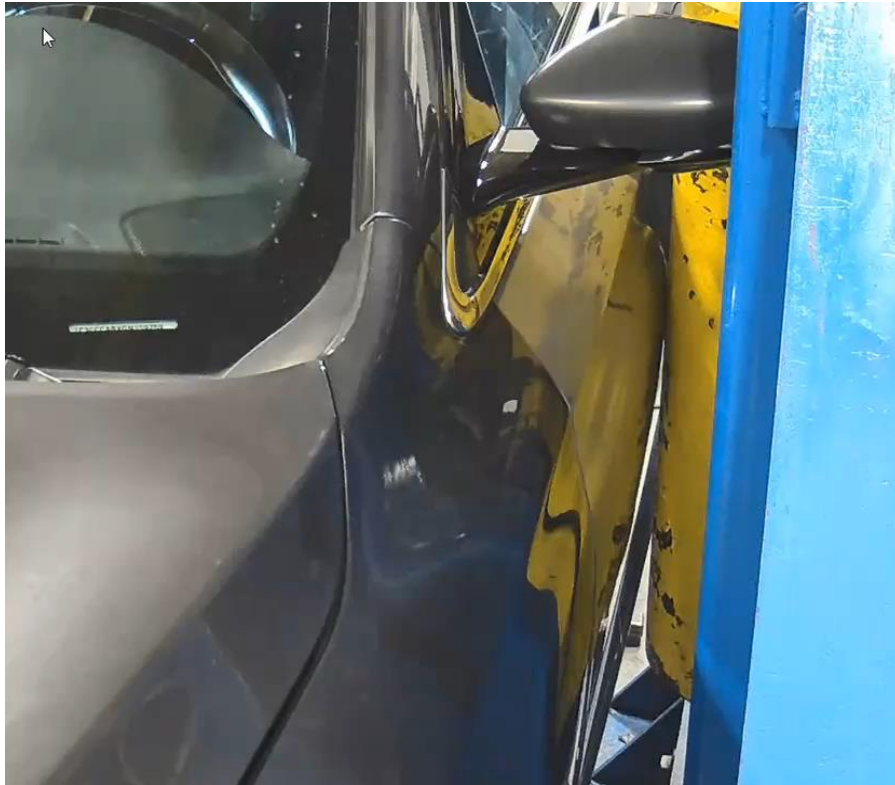
*The safety performance of the LW door was evaluated using the FMVSS 214 Static Test.*

# Technical Accomplishments

## FMVSS 214 Static Test



### LW Door Test Video



*The safety performance of the LW door was evaluated using the FMVSS 214 Static Test. The video illustrates the deformation which took place during the FMVSS 214 static test of the LW Door*

# Technical Accomplishments

## FMVSS 214 Static Test

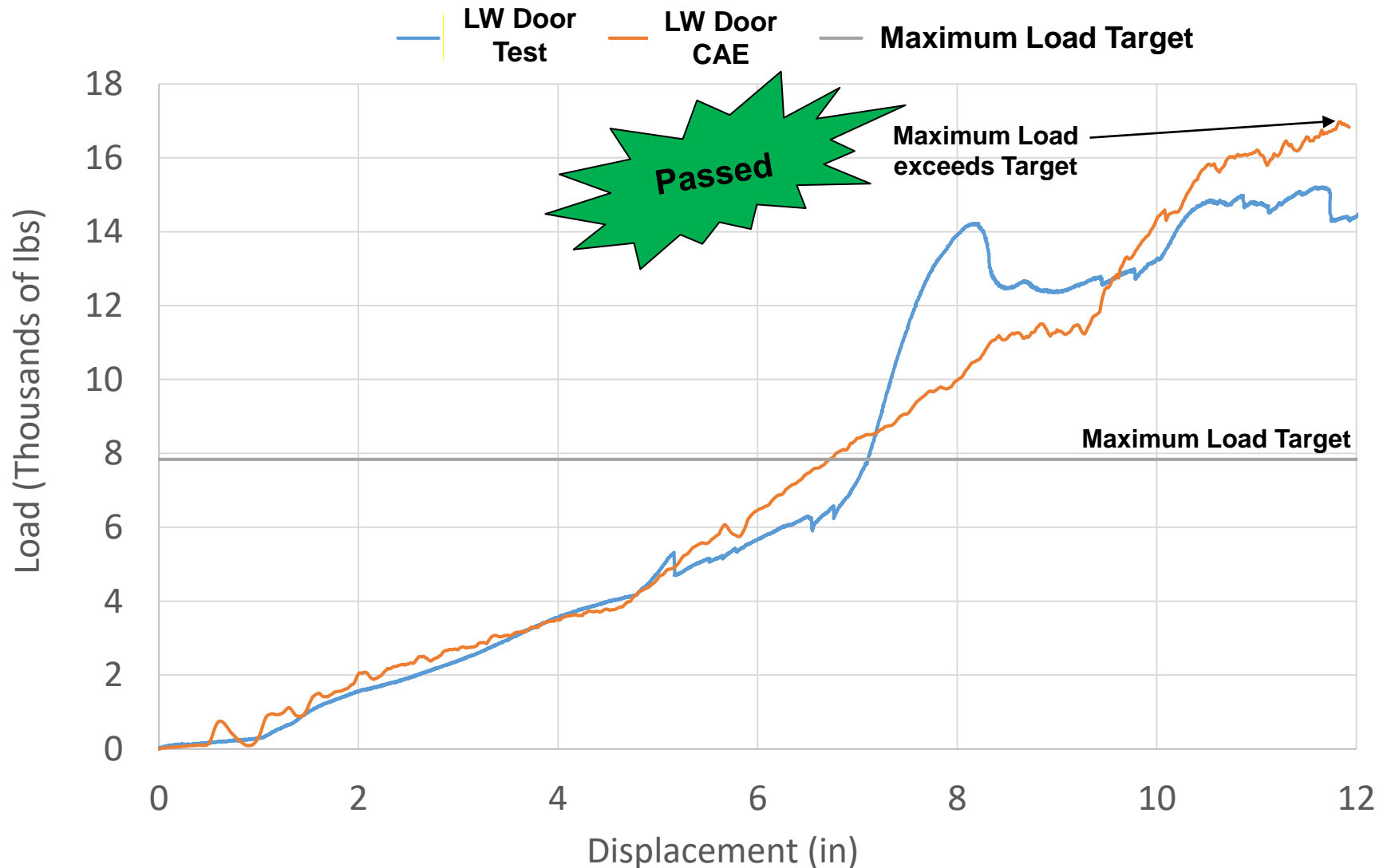


*The graph illustrates the energy absorption characteristics of LW door exceeded the minimum FMVSS 214 energy absorption values at 6" and 12" displacement.*



# Technical Accomplishments

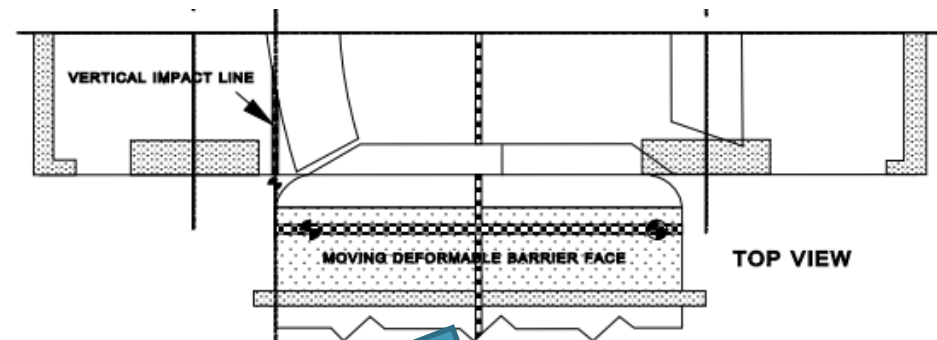
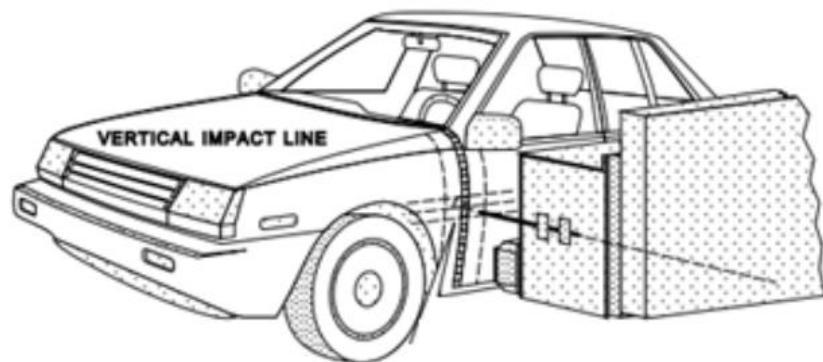
## FMVSS 214 Static Test



The graph illustrates the LW door CAE and FMVSS 214 Static Test exceeded the maximum Load Target.

# Technical Accomplishments

## NCAP Barrier Side Impact – FMVSS 214 Dynamic



**NCAP Side Rating as Reported by FCA  
(tests conducted at FCA's Chelsea Proving Grounds)**

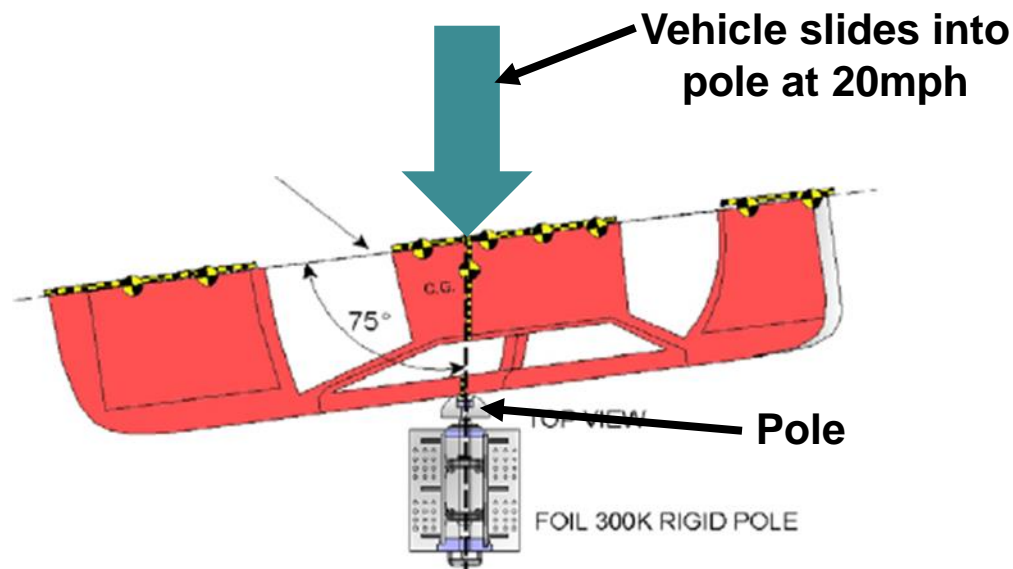
VC23650 – Star Rating					
38.5 MPH MDB Side Impact		VC23650		VC23650	
		50 <sup>th</sup> Front (ES-2re)		5 <sup>th</sup> Rear (SID-IIs)	
Injury Assessment Criteria	Unit	IAV	Injury Risk	IAV	Injury Risk
HIC (36)	-	129.3	0.0002	269.9	0.061
Upper rib deflection	mm	20.8	0.0299		
Middle rib deflection	mm	21.6	0.0322		
Lower rib deflection	mm	26.2	0.0483		
Abdominal force	N	921.2	0.0167		
Public force/Acetabular and Iliac force	N	1051.5	0.0016	2873.4	0.0265
RSR & JOINT PROBABILITY OF INJURY		0.44	0.066	0.021	0.032
Star Rating		***** (5.33)		***** (5.68)	



*The LW Door achieved a 5-Star Rating based on the 38.5 MPH NCAP Barrier Side Impact Test results*

# Technical Accomplishments

## NCAP 5<sup>th</sup> Pole Side Impact – FMVSS 214 Dynamic



Test Conducted by FCA at Chelsea Proving Ground

VC21355 – Star Rating			
20 MPH Oblique Pole Impact		VC21355	
		50 <sup>th</sup> Front (SID-IIs)	
Injury Assessment Criteria	Unit	IAV	Injury Risk
HIC (36)	–	232.1	0.0034
Combined acetabular and iliac force	N	3342.1	0.0405
RSR & JOINT PROBABILITY OF INJURY		0.029	0.044
Star Rating		***** (5.56)	

5-Star  
Achieved

The LW Door achieved a 5-Star Rating based on the 20 MPH NCAP 5<sup>th</sup> Pole Side Impact Test results

# Technical Accomplishments

## NCAP 5 Star Overall Rating

- Based on NCAP side impact tests performed a 5 star side impact rating was achieved

### Test Conducted by FCA at Chelsea Proving Grounds

		US NCAP Side Rating		
NCAP Mode		Occupant Rating		Mode Rating
Frontal	Driver Passenger	n/a n/a	-	-
Side	Front Pole Front MBD Rear MBD	5.56 5.33 5.68	5.38	***** (5.53)
Rollover		n/a	-	-
Overall Vehicle Rating				-

**Side Impact Tests**

**Individual Test Rating**

**Combined Side Impact Rating  
(comfortably exceeds  
5 Star target)**

*The LW Door achieved a NCAP 5-Star Overall Rating based on the test results conducted at the FCA Chelsea Proving Grounds.*



# Technical Accomplishments

## Durability Hardware Slam

Hardware Slam test is repetitive opening and closing of the door. The number of cycles represents vehicle life.



*The durability of the LW Door was evaluated using the Hardware Slam test*

# Technical Accomplishments

## Durability Hardware Slam

### Initial Hardware Slam Test

- Visible crack in upper hinge area
- Root cause was door shifting during test



**Small Crack on Inner Panel in hinge area**



### 2nd Hardware Slam Test – No Cracks

- Strengthened extrusion hinge reinforcement by increasing wall thickness to retain higher hinge bolt torque
- Removed paint on inner panel hinge surface to represent production



*Initial hardware slam test results resulted in a small crack on the inner panel in hinge area. The wall thickness of the hinge reinforcement was increased and the test was successfully repeated to resolve the concern.*



# Technical Accomplishments

## Comparative Life Cycle Analysis



- Ultralight Door Life Cycle Analysis was completed using ISO 14040/44 and CSA Group 2014 LCA Guidance Document for Auto Parts
- Results were published in the Journal for Lifecycle Assessment, August 2018  
<http://link.springer.com/article/10.1007/s11367-018-1515-z>

### **Results (reduction relative to baseline steel door shown)**

#### **With Powertrain Adaptation**

CO<sub>2</sub> eq. Reduction: 6.0 g CO<sub>2</sub>/km (9.6 g CO<sub>2</sub>/mile)

Total Power eq. Reduction: 86 kJ/km (138 kJ/mile)

#### **Without Powertrain Adaption**

CO<sub>2</sub> eq. Reduction: 2.8 g CO<sub>2</sub>/km (4.5 g CO<sub>2</sub>/mile)

Total Power eq. Reduction: 40 kJ/km (64 kJ/mile)

## Response to reviewer comments to 2017 presentation

*Results associated with the Ultralight Door Project were not presented at the 2018 AMR*

	Reviewer Comment	Response
1	Clear presentation of the actual costs in each component technologies would have been extraordinarily welcome in the presentation	Slide 33
2	The project started with three concepts of different materials to include Al, Mg, and CF composites, the reviewer suggested that the down selection process and decision matrix be provided to the review process	Slide 14

## Cost/lb-saved by Subsystem

	Baseline Door (kg)	Lightweight Door (kg)	Mass Reduction (kg)	Mass Reduction (lbs)	Cost Delta (\$)	\$/lb-saved
Door Structure	16.95	9.32	7.63	16.82	74.10	4.40
Interior Trim Panel and Upper Trim	4.12	2.15	1.66	3.66	7.58	2.07
Glass Assembly	4.31	2.65	1.97	4.34	7.71	1.77
Window System/Door Module	2.85	1.80	1.05	2.32	-	0.00
Latch and Exterior Handle	1.46	0.62	0.84	1.85	-	0.00
Other	8.34	6.32	2.02	4.45	4.50	1.01
<b>Total</b>	<b>38.03</b>	<b>22.86</b>	<b>15.17</b>	<b>33.45</b>	<b>93.89</b>	<b>2.81</b>

# Collaboration & Coordination



## **Vehma Eng. & Prototype**

Recipient, responsible for DIW and CAE analysis and prototype build of DIW, complete door assemblies and integration with FCA production vehicles.

## **Magna International**

Subrecipient, responsible for door architecture and engineering, BOM, weight tracking, cost modeling door assembly/integration, side glass development and coordination of Subrecipients.

## **Magna Closures**

Subrecipient, responsible for Door Module engineering and prototype and integration of SmartLatch.

## **Grupo Antolin NA**

Subrecipient, responsible for engineering and prototype manufacture of interior trim & packaging of electronic latch functionality

## **FCA US LLC**

Subrecipient, responsible for component and vehicle-level testing and speakers, as well as door functionality to facilitate commercialization opportunity.

## **Promatek Research Centre**

Subcontractor responsible for manufacture of 7xxx series warm formed door beam.

## **Alpine Electronics**

Supplier of neodymium magnet speakers to FCA

## **Arplas USA LLC**

Subcontractor responsible for DIW subassembly using projection welding process equipment.

## **Corning Glass**

Subcontractor responsible for the manufacture of Gorilla Glass test panels and laminated prototype moveable glass.

## **Lindita Bushi LLC**

Subcontractor responsible for conducting Life Cycle Analysis, documenting environmental benefit.

## **MGA Research**

Subcontractor responsible for conducting structural stiffness and durability tests.



# Remaining Challenges and Barriers

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Project has been completed.

# Proposed Future Research

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Project has been completed.

# Summary



<u>Item</u>	<u>Baseline Door</u>	<u>Ultralight Door</u>
Total Mass	38.03 kg	22.86 kg
Performance	5-star	5 star (equivalent)
DIW	Steel-intensive	Aluminum-intensive
Glass	Laminated soda lime	Laminated Gorilla glass
Latch	Mechanical	Electronic SmartLatch
Door Module	Conventional	Integrated glass channels
Door Beam	Boron Steel	7xxx Aluminum
Interface	CAN-bus	LIN- and CAN-bus
Incremental Cost	Reference	Modest Increase, +\$2.81/lb saved